ENERGY UP IN SMOKE

THE CARBON FOOTPRINT OF INDOOR CANNABIS PRODUCTION

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The report can be downloaded from: http://evan-mills.com/energy-associates/Indoor.html

On occasion, previously unrecognized spheres of energy use come to light. Important examples include the pervasive air leakage from ductwork in homes, the bourgeoning energy intensity of computer datacenters, and the electricity "leaking" from millions of small power supplies and other equipment. Intensive periods of investigation, technology R&D, and policy development gradually ensue in the wake of these discoveries.

The emergent industry of indoor Cannabis production appears to have joined the list. This report presents a model of the modern-day production process—based on public sources and equipment vendor data—and provides national scoping estimates of the energy use, costs, and greenhouse-gas emissions associated with this activity in the United States.[1]

Large-scale industrialized and highly energy-intensive indoor cultivation of Cannabis is a relatively new phenomenon, driven by criminalization, pursuit of security, and the desire for greater process control and yields.[2,3] The practice occurs in every state,[4] and the 415,000 indoor plants eradicated in 2009[5] represent only the tip of the iceberg.

Aside from sporadic news reports,[6,7] policymakers and consumers possess little information on the energy implications of this practice.[8] Substantially higher electricity demand growth is observed in areas reputed to have extensive indoor Cannabis cultivation. For example, following the legalization of cultivation for medical purposes in California in 1996, Humboldt County experienced a 50% rise in per-capita residential electricity use compared to other areas.[9] Cultivation is today legal in 17 states, albeit not federally sanctioned. In California, 400,000 individuals are authorized to grow Cannabis for personal medical use, or sale to 2,100 dispensaries.[10] Official estimates of total U.S. production varied from 10,000 to 24,000 metric tons per year in 2001,[4] making it the nation's largest crop by value.[11] As of 2006, one third of national indoor production was estimated to occur in California.[12] Based on a rising number of consumers (6.6% of U.S. population above the age of 12),[13] national production in 2011 is estimated for the purposes of this study at 17,000 metric tons, one-third occurring indoors.[14]

Driving the large energy requirements of indoor production facilities are lighting levels matching those found in hospital operating rooms (500-times greater than recommended for reading) and 30 hourly air changes (6-times the rate in high-tech laboratories, and 60-times the rate in a modern home). Resulting electricity intensities are 200 watts per square foot, which is on a par with modern datacenters. Indoor carbon dioxide (CO_2) levels are often raised to four-times natural levels in order to boost plant growth.

Specific energy uses include high-intensity lighting, dehumidification to remove water vapor, space heating during non-illuminated periods and drying, irrigation water pre-heating, generation of CO_2 by burning fossil fuel, and ventilation and air-conditioning to remove waste heat. Substantial energy inefficiencies arise from air cleaning, noise and odor suppression, and inefficient electric generators used to avoid conspicuous utility bills.

Based on these operational factors, the energy requirements to operate a standard production module—a 4x4x8 foot chamber—are approximately 13,000 kWh/year of electricity and 1.5 x 10^6 BTU/year of fossil fuel. A single grow house can contain 10 or more such modules. Power use scales to about 20 TWh/year nationally (including off-grid production and power theft), equivalent to that of 2 million average U.S. homes. This corresponds to 1% of national electricity consumption or 2% of that in households—or the output of 7 large electric power plants.[15] This energy, plus transportation fuel, is valued at $5 billion annually, with associated emissions of 17 million metric tons of CO_2—equivalent to that of 3 million average American cars. (See Figure 1 and Tables 1-5.)

Fuel is used for several purposes, in addition to electricity. Carbon dioxide, generated industrially[16] or by burning propane or natural gas, contributes about 2% to the carbon footprint. Vehicle use for production and distribution contributes about 15% of total emissions, and represents a yearly expenditure of $1 billion. Off-grid diesel- and gasoline-fueled electric generators have emissions burdens that are three- and four-times those of average grid electricity in California. It requires 70 gallons of diesel fuel to produce one indoor Cannabis plant, or 140 gallons with smaller, less-efficient gasoline generators.

In California, the top-producing state, indoor cultivation is responsible for about 3% of all electricity use or 8% of household use, somewhat higher than estimates previously made for British Columbia[17] This corresponds to the electricity use of 1 million average California homes, greenhouse-gas emissions equal to those from 1 million average cars, and energy expenditures of $3 billion per year. Due to higher electricity prices and cleaner fuels used to make electricity, California incurs 70% of national energy costs but contributes only 20% of national CO_2 emissions from indoor Cannabis cultivation.

From the perspective of individual consumers, a single Cannabis cigarette represents 2 pounds of CO_2 emissions, an amount equal to running a 100-watt light bulb for 17 hours assuming average U.S. electricity emissions (or 30 hours on California's cleaner grid). The emissions associated with one kilogram of processed Cannabis are equivalent to those of driving across country 5 times in a 44-mpg car. One single production module doubles the electricity use of an average U.S. home and triples that of an average California home. The added electricity use is equivalent to running about 30 refrigerators. Producing one kilogram of processed Cannabis results in 3,000 kilograms of CO_2 emissions.

The energy embodied in the production of inputs such as fertilizer, water, equipment, and building materials is not estimated here and should be considered in future assessments.

Minimal information and consideration of energy use, coupled with adaptations for security and privacy, lead to particularly inefficient configurations and correspondingly elevated energy use and greenhouse-gas emissions. If improved practices applicable to commercial agricultural greenhouses are any indication, such large amounts of energy are not required for indoor Cannabis production.[18] Cost-effective efficiency improvements of 75% are conceivable, which would yield energy savings of about $25,000/year for a generic 10-module operation. Shifting cultivation outdoors virtually eliminates energy use (aside from transport), although, when mismanaged, the practice imposes other environmental impacts.[19] Elevated moisture levels associated with indoor cultivation can cause extensive damage to buildings.[20] Electrical fires are an issue as well.[21] For legally sanctioned operations, the application of energy performance standards, efficiency incentives and education, coupled with the enforcement of appropriate construction codes could lay a foundation for public-private partnerships to reduce undesirable impacts.[22] Were compliant operations to receive some form of independent certification and product labeling, environmental impacts could be made visible to otherwise unaware consumers.

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Current indoor Cannabis production and distribution practices result in prodigious energy use, costs, and greenhouse-gas pollution. The hidden growth of electricity demand in this sector confounds energy forecasts and obscures savings from energy efficiency programs and policies. More in-depth analysis and greater transparency in the energy impacts of this practice could improve decision-making by policymakers and consumers alike.

Figure 1. Carbon Footprint of Indoor Cannabis Production

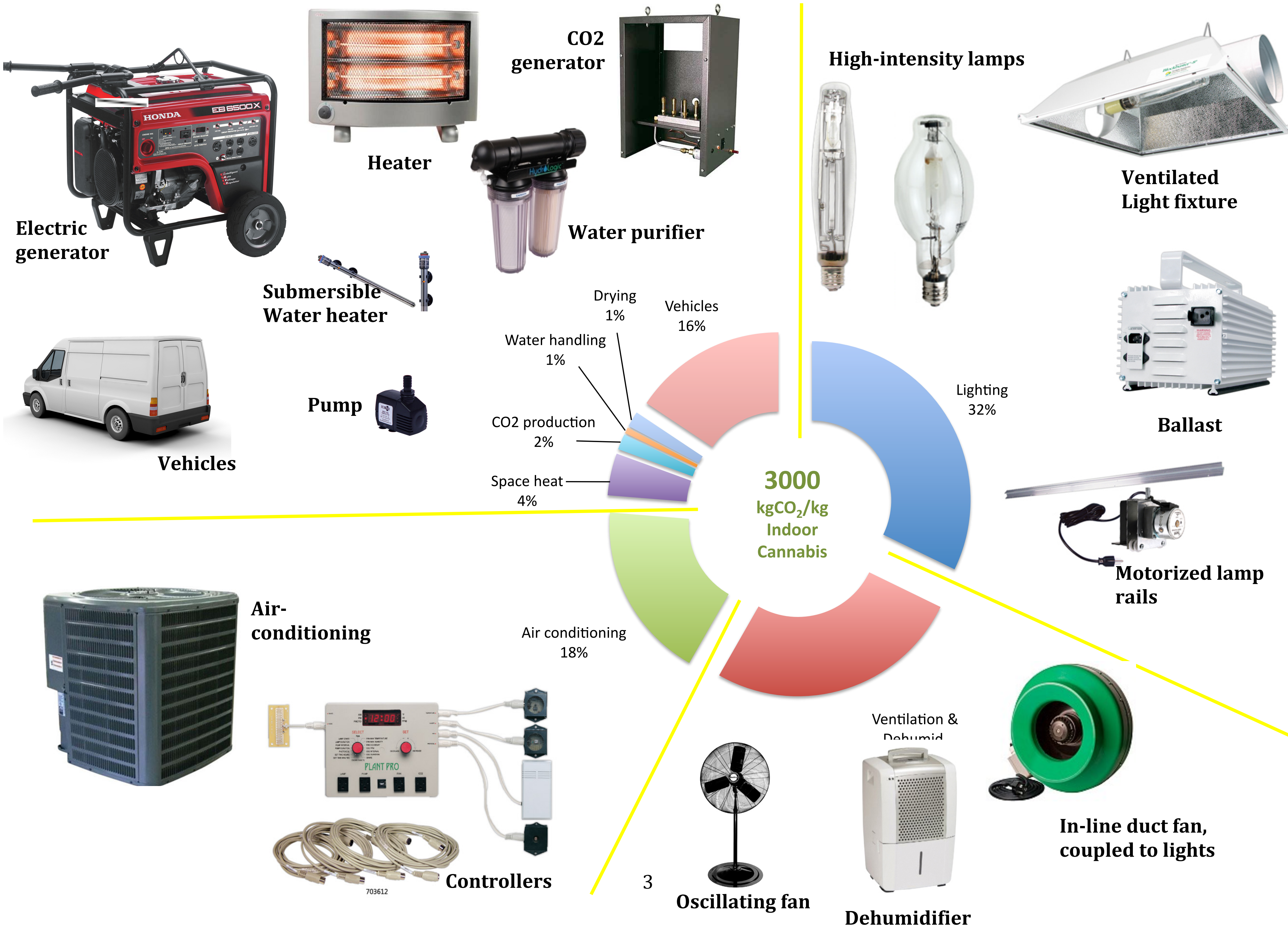

Table 1. Configuration, Environmental Conditions, and Setpoints		
Production parameters		
Growing module	16	square feet (excl. walking area)
Number of modules in a room	10	
Area of room	240	square feet
Cycle duration	78	days
Production continuous throughout the year	4.7	cycles
Illumination	*Leaf phase*	*Flowering phase*
Lamp type	Metal halide	High-pressure sodium
Watts/lamp	600	1000
Ballast losses (mix of magnetic & digital)	13%	13%
Lamps per growing module	1	1
Hours/day	18	12
Days/cycle	18	60
Daylighting	none	none
Ventilation		
Ducted luminaires with "sealed" lighting compartment	150	CFM/1000W of light (free flow)
Room ventilation (supply and exhaust fans)	30	ACH
Filtration	Charcoal filters on exhaust; HEPA on supply	
Oscilating fans: per module, while lights on	1	
Water		
Application	40	gallons/room-day
Heating	Electric submersible heaters	
	75	F
Space conditioning		
Indoor setpoint - day	82	F
Indoor setpoint - night	68-70	F
AC efficiency	10.0	SEER
Dehumidification	7x24	hours
CO_2 production - target concentration (mostly natural gas combustion in space)	1500	ppm
Electric space heating	when lights off to maintain indoor setpoint	
Target indoor humidity conditions	40-50%	
Fraction of lighting system heat production removed by luminaire ventilation	30%	
Ballast location	Outside conditioned space	
Drying		
Space conditioning, oscillating fans, maintaining 50% RH, 70-80F	7	days
Electricity supply		
grid	85%	
grid-independent generation (mix of diesel, propane, and gasoline)	15%	
Vehicle use		
workers during production	2089	vehicle miles/cycle
wholesale distribution	750	vm/cycle
retail distribution (1 bounce)	3520	vm/cycle

Table 2. Assumptions & conversion factors		
Service Levels		
Illuminance*	25-100,000	lux
Airchange rates*	30	changes per hour
Operations		
Cycle duration**	78	days
Cycles/year**	4.7	continuous production
Production module area*	16	square feet (excl. walking area)
Production module volume**	192	cubic feet
Airflow**	96	cubic feet per minute
Modules per room*	10	
Lighting		
Leafing phase		
Lighting on-time*	18	hrs/day
Duration*	18	days/cycle
Flowering phase		
Lighting on-time*	12	hrs/day
Duration*	60	days/cycle
Drying		
Hours/day*	24	hrs
Duration*	7	days/cycle
Equipment		
Average air-conditioning age	5	years
Air conditioner efficiency (SEER)	10	Minimum standard as of 1/2006
Fraction of lighting system heat production removed by luminaire ventilation	30%	
Diesel generator efficiency*	27%	55kW
Propane generator efficiency*	25%	27kW
Gasoline generator efficiency*	15%	5.5kW
Fraction of total prod'n with generators*	15%	
Water use [indoor]*	1	gallons/day-plant
Transportation: Production phase (10 modules)	25	miles roundtrip
Daily service (1 vehicle)	78	trips/cycle. Assume 20% live on site
Biweekly service (2 vehicles)	11	trips/cycle
Harvest (2 vehicles)	10	trips/cycle
Total vehicle miles**	2089	vehicle miles/cycle
Transportation: Distribution		
Amount transported wholesale	5	kg per trip
Mileage (roundtrip)	750	vm/cycle
Retail (0.25oz x 5 miles roundtrip)	3520	vm/cycle
Total**	4270	vm/cycle
Fuel economy, typical car [a]	22	mpg
Annual emissions, typical car [a]	5195	kg CO2
	0.416	kg CO2/mile
Annual emissions, 44-mpg car**	2598	kg CO2
	0.208	kg CO2/mile
Cross-country US mileage	2790	miles

Fuels		
Propane [b]	91,033	BTU/gallon
Diesel [b]	138,690	BTU/gallon
Gasoline [b]	124,238	BTU/gallon
Electric Generation Mix*		
Grid	85%	share
Diesel generators	8%	share
Propane generators	5%	share
Gasoline generators	2%	share
Emissions Factors		
Grid electricity - US [c]	0.609	kgCO2/kWh
Grid electricity - CA [c]	0.384	kgCO2/kWh
Grid electricity - non-CA US [c]	0.648	kgCO2/kWh
Diesel generator**	0.922	kgCO2/kWh
Propane generator**	0.877	kgCO2/kWh
Gasoline generator**	1.533	kgCO2/kWh
Blended generator mix**	0.989	kgCO2/kWh
Blended on/off-grid generation - CA**	0.475	kgCO2/kWh
Blended on/off-grid generation - US**	0.666	kgCO2/kWh
Propane combustion	63.1	kgCO2/MBTU
Prices		
Electricity price - grid (California - PG&E) [d]	$0.390	per kWh (Tier 5)
Electricity price - grid (US, excl. CA) [e]	$0.127	per kWh
Electricity price - off-grid**	$0.390	per kWh
Electricity price - blended on/off - CA**	$0.390	per kWh
Electricity price - blended on/off - US**	$0.166	per kWh
Propane Price [f]	$2.20	per gallon
Gasoline Price - US average [f]	$3.68	per gallon
Diesel Price - US average [f]	$3.98	per gallon
Wholesale price of Cannabis [g]	$4,000	$/kg
Production		
Plants per production module*	4	
Net production per production module [h]	0.7	kg/cycle
US production (2011) [i]	16,974	metric tonnes/y
California production (2011) [i]	5,922	metric tonnes/y
Fraction produced indoors [i]	33%	
US indoor production modules**	1,727,283	
Calif indoor production modules**	602,597	
Cigarettes per kg**	3,000	
Other		
Average new refrigerator	450	kWh/year
	173	kgCO2/year (US average)
Electricity use of a typical US home - 2009 [j]	11,646	kWh/year
Electricity use of a typical California home - 2009 [k]	6,961	kWh/year

* trade and product literature; interviews with equipment vendors
** calculated from other values

Table 3. Carbon footprint of indoor Cannabis Production

(Average US conditions)

	kWh/kg	kgCO2 emissions/kg	
Lighting	1,479	985	32.2%
Ventilation & Dehumid.	1,197	797	26.1%
Air conditioning	827	551	18.0%
Space heat	197	131	4.3%
CO_2 production	54	49	1.6%
Water handling	28	19	0.6%
Drying	73	48	1.6%
Vehicles		479	15.7%
Total	3,855	**3,059**	100.0%

Note: "CO2 production" represents combustion fuel to make on-site CO2. Assumes 15% of electricity is produced in off-grid generators. As the fuels used for CO2 contain moisture, additional dehumidification is required (and allocated here to the CO2 energy row). Air-conditioning associated with CO2 production (as well as for lighting, ventilation, and other incidentals) is counted in the air-conditioning category.

Table 4. Equivalencies									
Indoor Cannabis production consumes...	**3%**	of California's total electricity, and	**8%**	of California's household electricity	**1%**	of total US electricity, and	**2%**	of US household electricity	
U.S. Cannabis production & distribution energy cost...	**$5**	Billion, and results in the emissions of	**17**	million tonnes per year of greenhouse gas emissions (CO_2)	equal to the emissions of	**3**	million average cars		
U.S. electricity use for Cannabis production is equivalent to that of...	**2**	million average US homes							
California Cannabis production and distribution energy cost	**$3**	Billion, and results in the emissions of	**4**	million tonnes per year of greenhouse gas emissions (CO_2)	equal to the emissions of	**1**	million average cars		
California electricity use for Cannabis production is equivalent to that of...	**1**	million average California homes							
A typical 4x4x8-foot production module, accomodating four plants at a time, consumes as much electricity as...	**1**	average U.S. homes, or	**2**	average California homes	or	**28**	average new refrigerators		
Every 1 kilogram of Cannabis produced using national-average grid power results in the emissions of...	**2.8**	tonnes of CO_2	equivalent to	**4.9**	cross-country trips in a 44mpg car				
Every 1 kilogram of Cannabis produced using a prorated mix of grid and off-grid generators results in the emissions of...	**3.1**	tonnes of CO_2	equivalent to	**5.3**	cross-country trips in a 44mpg car				
Every 1 kilogram of Cannabis produced using off-grid generators results in the emissions of...	**4.3**	tonnes of CO_2	equivalent to	**7.4**	cross-country trips in a 44mpg car				
Transportation (wholesale+retail) consumes...	**52**	gallons of gasoline per kg	or	**$1**	billion dollars annually, and	**479**	kilograms of CO_2 per kilogram of final product		
One Cannabis cigarette is like driving...	**15**	miles in a 44mpg car	emitting about	**2**	pounds of CO_2, which is equivalent to operating a 100-watt light bulb for	**17**	hours		
Of the total wholesale price...	**24%**	is for energy (at average U.S. prices)							

Table 5. Indicators (Average US conditions)	**per cycle, per production module**	**per year, per production module**	
Energy Use			
Connected Load		3,039	watts/module
Power Density		190	watts/ft2
Elect	2,698	12,626	kWh/module
Fuel to make CO2	0.3	1.5	MBTU
Transportation fuel	37	172	gallons
On-grid results			
Energy cost	592	2,770	$/module
Energy cost		846	$/kg
Fraction of wholesale price		21%	
CO2 emissions	1,988	9,302	kg
CO2 emissions		2,840	kg/kg
Off-grid results (diesel)			
Energy cost	1,196	5,595	$/module
Energy cost		1,708	$/kg
Fraction of wholesale price		43%	
CO2 emissions	3,012	14,094	kg
CO2 emissions		4,303	kgCO2/kg
Blended on/off grid results			
Energy cost	682	3,194	$/module
Energy cost		975	$/kg
Fraction of wholesale price		24%	
CO2 emissions	2,141	10,021	kg
CO2 emissions		3,059	kgCO2/kg
Of which, indoor CO2 production	9	42	kgCO2
Of which, vehicle use			
Fuel use			
During Production		14	gallons/kg
Distribution		39	gallons/kg
Cost			
During Production		$50	$/kg
Distribution		$143	$/kg
Emissions			
During Production		124	kgCO2/kg
Distribution		355	kgCO2/kg

Table 6. Model	**Energy type**	**Penetration**	**Rating**	**Number of 4x4x8-foot production modules served**	**Input energy per module**	**Units**	**Hours/day (leaf phase)**	**Hours/day (flower phase)**	**Days/cycle (leaf phase)**	**Days/cycle (flower phase)**	**kWh / cycle**	**kWh/year per production module**
Light												
Lamps (HPS)	elect	100%	1000	1	1000	W		12		60	720	3,369
Ballasts (losses)	elect	100%	13%	1	130	W		12		60	94	438
Lamps (MH)	elect	100%	600	1	600	W	18		18		194	910
Ballast (losses)	elect	100%	13%	1	78	W	18		18		25	118
Motorized rail motion	elect	5%	5.5	1	0.3	W	18	12	18	60	0	1
Controllers	elect	50%	10	10	1	W	24	24	18	60	2	9
Ventilation and moisture control												
Luminare fans (sealed from conditioned space)	elect	100%	454	10	45	W	18	12	18	60	47	222
Main room fans - supply	elect	100%	242	8.1	30	W	18	12	18	60	31	145
Main room fans - exhaust	elect	100%	242	8.1	30	W	18	12	18	60	31	145
Circulating fans (18")	elect	100%	130	1	130	W	24	24	18	60	242	1,134
Dehumidification	elect	100%	1,035	4	259	W	24	24	18	60	484	2,267
Controllers	elect	50%	10	10	1	W	24	24	18	60	2	9
Spaceheat												
Resistance heat [when lights off]		90%	1,850	10	167	W	6	12	18	60	138	645
Carbon Dioxide												
Parasitic electricity	elect	50%	100	10	5	W	18	12	18	60	5	24
AC (see below)	elect	100%										
In-line heater	elect	5%	115	10	0.6	W	18	12	18	60	1	3
Dehumidification (10% adder)	elect	50%	104	0.4	26	W	18	12	18	60	27	126
Monitor/control	elect	50%	50	10	3	W	24	24	18	60	5	22
Water												
Heating	elect	100%	300	10	30	W	18	12	18	60	19	89
Pumping - irrigation	elect	100%	55	10	5.5	W	1	1	18	60	0	2
Drying												
Dehumidification	elect	75%	1,850	10	139	W		24		7	23	109
Circulating fans	elect	100%	130	5	26	W		24		7	4	20
Heating	elect	75%	1,850	10	139	W		24		7	23	109
Electricity subtotal	elect										2,119	9,918
Air-conditioning											579	2,709
Lighting loads											239	1,117
Loads that can be remoted	elect	100%	1,180	10	118	W					221	1,034
Loads that can't be remoted	elect	100%	450	10	45	W					84	394
CO2-production heat removal	elect	50%	1,118	16.7	34	W	18	12	18	60	35	164
Electricity Total	**elect**				**3,039**	**W**					**2,698**	**12,626**
ON-SITE FUEL	**Units**	**Technology Mix**	**Rating (BTU/ hour)**	**Number of 4x4x8-foot production modules served**	**Input energy per module**		**Hours/day (leaf phase)**	**Hours/day (flower phase)**	**Days/cycle (leaf phase)**	**Days/cycle (flower phase)**	**MBTU or kgCO2/cycle**	**MBTU or kgCO2/year**
On-site CO2 production												
Energy use	propane	45%	11,176	16.7	671	BTU/ho	18	12	18	60	0.3	1.5
CO2 production --> emissions	kg/CO2										20	93
Externally produced Industrial CO2		5%		1	0.011	gallonsCO2/hr	18	12	18	60	1	3
Weighted-average on-site / purchased	kgCO2										2	10
Weighted average on-site / purchased	kg CO2										9	42

Notes for Tables

[a]. U.S. Environmental Protection Agency. "Emission Facts: Average Annual Emissions and Fuel Consumption for Passenger Cars and Light Trucks." http://www.epa.gov/oms/consumer/f00013.htm [accessed February 5, 2011]

[b]. *Energy Conversion Factors,* U.S. Department of Energy, http://www.eia.doe.gov/energyexplained/index.cfm?page=about_energy_units [Accessed February 5, 2011]

[c]. U.S. Department of Energy, "Voluntary Reporting of Greenhouse Gases Program" http://www.eia.doe.gov/oiaf/1605/ee-factors.html [Accessed February 7, 2011]. CA: "Marnay, C., D. Fisher, S. Murtishaw, A. Phadke, L. Price, and J. Sathaye. 2002. "Estimating Carbon Dioxide Emissions Factors for the California Electric Power Sector." Lawrence Berkeley National Laboratory Report No. 49945. http://industrial-energy.lbl.gov/node/148

[d]. PG&E residential tariff as of 1/1/11, Tier 5 http://www.pge.com/tariffs/ResElecCurrent.xls [Accessed February 5, 2011]. In practice a wide mix of tariffs apply, but the relative shares are not known.

[e]. State-level residential prices, weighted by Cannabis production from [Reference 4], with actual tariffs and U.S. Energy Information Administration, "Average Retail Price of Electricity to Ultimate Customers by End-Use Sector, by State", http://www.eia.doe.gov/electricity/epm/table5_6_a.html [Accessed February 7, 2011]

[f]. U.S. Energy Information Administration, Gasoline and Diesel Fuel Update (as of 2/14/2011) - see http://www.eia.gov/oog/info/gdu/gasdiesel.asp Propane prices - http://www.eia.gov/dnav/pet/pet_pri_prop_a_EPLLPA_PTA_dpgal_m.htm [Accessed April 3, 2011]

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[h]. Toonen, M., S. Ribot, and J. Thissen. 2006. “Yield of Illicit Indoor Cannabis Cultivation in the Netherlands.” *Journal of Forensic Science*, 15(5):1050-4. http://www.ncbi.nlm.nih.gov/pubmed/17018080

[i]. See Reference 14 for derivation.

[j]. Total U.S. Electricity Sales: U.S. Energy Information Administration, "Retail Sales of Electricity to Ultimate Customers: Total by End-Use Sector" http://www.eia.gov/cneaf/electricity/epm/table5_1.html [Accessed March 5, 2011]

[k]. California Energy Commission. "Energy Almanac." http://energyalmanac.ca.gov/electricity/us_per_capita_electricity.html [Accessed February 19, 2011]. See also Total California Electricity Sales: California Energy Commission. 2009. *California Energy Demand: 2010-2020 -- Adopted Forecast.* Report CEC-200-2009-012-CMF), December 2009 (includes self-generation).

References

1. This report presents a model of typical production methodologies and associated transportation energy use. Data sources include equipment manufacturer data, trade media, the open literature, and interviews with horticultural supply vendors. All assumptions used in the analysis are presented in Table 2. The resultant normalized (per-kilogram) energy intensity is driven by the target environmental conditions, production process, and equipment efficiencies. While less energy-intensive processes are possible (either with lower per-unit-area yields or more efficient equipment and controls), much more energy-intensive scenarios are also possible (e.g., rooms using 100% recirculated air with reheat, hydroponics, and loads not counted here such as well-water pumps and water purification systems). The assumptions about vehicle energy use are likely conservative, given the longer-range transportation associated with interstate distribution. Some localities (very cold and very hot climates) will see much larger shares of production indoors, and have higher space-conditioning energy demands than the typical conditions assumed here. Some authors [See Plecas, D. J. Diplock, L. Garis, B. Carlisle, P. Neal, and S. Landry. *Journal of Criminal Justice Research,* Vol. 1 No 2., p. 1-12.] suggest that the assumption of 0.75kg yield per production module per cycle is an over-estimate. Were that the case, the energy and emissions values in this report would be even higher, which is hard to conceive. Additional key uncertainties are total production and the indoor fraction of total production (see note 14), and the corresponding scaling up of relatively well-understood intensities of energy use per unit of production to state or national levels by weight of final product. Greenhouse-gas emissions estimates are in turn sensitive to the assumed mix of on- and off-grid power production technologies and fuels, as off-grid production tends to have substantially higher emissions per kilowatt-hour than grid power. Costs are a direct function of the aforementioned factors, combined with electricity tariffs, which vary widely across the country and among customer classes. More in-depth analyses could explore the variations introduced by geography and climate, alternate technology configurations, and production techniques.
2. U.S. Department of Justice. *National Drug Threat Assessment: 2010* http://www.justice.gov/ndic/pubs38/38661/marijuana.htm#Marijuana
3. World Drug Report: 2009. United Nations Office on Drugs and Crime, p. 97. http://www.unodc.org/unodc/en/data-and-analysis/WDR-2009.html For U.S. conditions, indoor yields per unit area are estimated as up to 15-times greater than outdoor yields.
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5. See http://www.justice.gov/dea/programs/marijuana.htm
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8. A study by RAND appears to have severely underestimated the true energy costs. See J. P. Caulkins. 2010. “Estimated Cost of Production for Legalized Cannabis.” RAND Working Paper, WR-764-RC. July. Although the study over-estimates the hours of lighting required,

it under-estimates the electrical demand and applies energy prices that fall far short of the inclining marginal-cost tariff structures applicable in many states, particularly California.

9. Lehman, P. and P. Johnstone. 2010. "The Climate-Killers Inside." *North Coast Journal*, March 11.
10. Harvey, M. 2009. "California Dreaming of Full Marijuana Legalisation." *The Sunday Times*, (September). http://business.timesonline.co.uk/tol/business/industry_sectors/health/article6851523.ece
11. See Gettman, *op cit.,* at ref 4.
12. See Gettman, *op cit.,* at ref 4.
13. U.S. Department of Health and Human Services, SAMHSA, 2009 National Survey on Drug Use and Health (September 2010). https://nsduhweb.rti.org/
14. Total Production: The only official domestic estimate of U.S. Cannabis production was 10,000 to 24,000 tonnes for the year 2001. Gettman (*op cit.,* at ref. 4) conservatively retained the lower value for the year 2006. This 2006 base is adjusted to 2011 values using 10.9%/year net increase in number of consumers between 2007 and 2009, per U.S. Department of Health and Human Services (*op cit.,* at ref. 12). The result is approximately 17 million tonnes of total production annually (indoor and outdoor). Indoor Share of Total Production: The three-fold changes in potency over the past two decades, reported by federal sources, are attributed at least in part to the shift towards indoor cultivation [See http://www.justice.gov/ndic/pubs37/37035/national.htm and Hudson *op cit.,* at ref 4]. A weighted-average potency of 10% THC (U.S. Office of Drug Control Policy. 2010. "Marijuana: Know the Facts"), reconciled with assumed 7.5% potency for outdoor production and 15% for indoor production implies 33.3%::67.7% indoor::outdoor production shares. For reference, as of 2008, 6% of eradicated plants were from indoor operations, which are more difficult to detect than outdoor operations. A 33% indoor share, combined with per-plant yields from Table 2, would correspond to a 4% eradication success rate for the levels reported (415,000 indoor plants eradicated in 2009) by the DEA (*op cit.,* at ref 5). Assuming 400,000 members of medical Cannabis dispensaries in California (each of which is permitted to cultivate), and 50% of these producing in the generic 10-module room assumed in this analysis, output would slightly exceed this study's estimate of total statewide production. In practice, significant indoor production is no doubt conducted outside of the medical marijuana system.
15. Koomey, J., et al. 2010. "Defining A Standard Metric for Electricity Savings." *Environmental Research Letters*, 5, doi:10.1088/1748-9326/5/1/014017.
16. Overcash, Y. Li, E. Griffing, and G. Rice. 2007. "A life cycle inventory of carbon dioxide as a solvent and additive for industry and in products." *Journal of Chemical Technology and Biotechnology*, 82:1023–1038.
17. Specifically, 2% of total Provincial electricity use or 6% of residential use, as reported by BC Hydro in Garis, L. 2008. "Eliminating Residential Hazards Associated with Marijuana Grow Operations and The Regulation of Hydroponics Equipment," British Columbia's Public Safety Electrical Fire and Safety Initiative, Fire Chiefs Association of British Columbia, 108pp. See also Bellett, G. 2010. "Pot Growers Stealing $100 million in Electricity: B.C. Hydro studies found 500 Gigawatt hours stolen each year." *Alberni Valley Times.* October 8. Analysis by B.C. Hydro in 2006 identified nearly 18,000 residential utility accounts in Vancouver with suspiciously high electricity use [see Garis 2008]. There were an estimated 10,000 indoor operations in B.C. in the year 2003, generating $1.24B in wholesale revenue [See Plecas et al., *op cit.,* at ref 1.].

18. See, e.g., this University of Michigan resource: http://www.hrt.msu.edu/energy/Default.htm
19. "Environmental Impacts of Pot Growth." 2009. *Ukiah Daily Journal*. (posted at http://www.cannabisnews.org/united-states-cannabis-news/environmental-impacts-of-pot-growth/)
20. For observations from the building inspectors community, see http://www.nachi.org/marijuana-grow-operations.htm
21. See Garis, L*., op cit.,* at ref 17.
22. The City of Fort Bragg, CA, has implemented elements of this in *TITLE 9 – Public Peace, Safety, & Morals,* Chapter 9.34. http://city.fortbragg.com/pages/searchResults.lasso?-token.editChoice=9.0.0&SearchType=MCsuperSearch&CurrentAction=viewResult#9.32.0